VOLUME 81 PAPER No. 754

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

JULY, 1955

AMERICAN SOCIETY OF CIVIL ENGINEERS FOUNDED 1852

ROCK WEATHERING CLASSIFICATION OF EXCAVATION SLOPES

by J. D. Welch, J.M. ASCE

SOIL MECHANICS AND FOUNDATIONS DIVISION

(Discussion open until November 1, 1955)

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

THIS PAPER

--represents an effort by the Society to deliver technical data direct from the author to the reader with the greatest possible speed. To this end, it has had none of the usual editing required in more formal publication procedures.

Readers are invited to submit discussion applying to current papers. For this paper the final date on which a discussion should reach the Manager of Technical Publications appears on the front cover.

Those who are planning papers or discussions for "Proceedings" will expedite Division and Committee action measurably by first studying "Publication Procedure for Technical Papers" (Proceedings Paper No. 290). For free copies of this Paper—describing style, content, and format—address the Manager, Technical Publications, ASCE.

This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

ROCK WEATHERING CLASSIFICATION OF EXCAVATION SLOPES

J. D. Welch, J. M. ASCE[1]

SYNOPSIS

The design of excavation backslopes in rock for the West Virginia Turnpike necessitated the classification of rock materials, sandstones and shales, with regard to weathering susceptibility. The A.S.T.M. - A.A.S.H.O. Standard test for magnesium sulfate soundness of rock was applied to this study, and qualitatively calibrated to existing natural weathering conditions of exposed rock. The empirical investigation resulted in a laboratory method to determine whether a rock material would be below average or above average weathering susceptibility. The results of the laboratory procedure were then employed in the design for all excavation slopes in rock.

INTRODUCTION

The history of construction in West Virginia contains numerable examples of landslides and rockfalls. This problem confronted those who were to plan and design the West Virginia Turnpike. The overall problem was further complicated by the necessary requirements for extreme safety and low maintenance contiguous to a revenue bond financed project, paid for by tolls. It was necessary to evaluate the physical properties of rock materials to be encountered in excavation backslopes such that they could be designed and constructed to achieve one phase of these safety and maintenance requirements, within reasonable economic latitudes.

The terrain through which the initial part of the turnpike is to pass, geologically consists of interbedded sandstones and shales of all degrees of hardness, and extreme variation in thickness of strata. Coal deposits are liberally distributed throughout this region. These sedimentary deposits are of the Maunch Chunk, Pottsville, Allegheny, Conemaugh and Monongahela Series. The highly irregular terrain was formed by erosion of the Appalachian Plateau, resulting essentially in horizontal bedding of the sedimentary rocks and a relatively shallow overburden of residual soils, with alluvial deposits in older stream and river valleys. The landslide or slope failure associated with deep soil deposits, or rock slides associated with tilted bedding were not a problem to be considered in establishing the design criteria. This does not mean that deep slides or rock falls were not encountered on the project, some located prior to construction and some during construction. These latter were of such character that they necessitated individual studies for solution and treatment. However, rockfalls and surface sloughing resulting from weathering of rock slopes were a problem requiring consideration in original overall slope design. The method of rock weathering classification for design

1. Chief Soils Engr., Howard, Needles, Tammen & Bergendoff, New York, N.Y.

of the rock slopes and how this classification was devised is then the general subject of this paper. It should be noted that for the purpose of this study, deposits of shales were considered as a rock formation.

Rock Slope Design Standards

The experience of the West Virginia State Road Commission[2] with backslopes in rock cut sections indicated that the sandstones and shales were each subject to extreme ranges of weathering action, dependent upon the particular deposit, but with time would eventually assume a stabilized condition if the weathered material remained upon the slope. The method of solution of the problem, from an economic standpoint, was not to excavate the rock face to a flat slope that was considered to be the ultimate stable slope. Any such excavation still exposed fresh rock surfaces to atmospheric conditions and some degree of weathering action would take place. A method was to be employed that accounted for this weathering action and still provided an overall stable slope.

This consideration resulted in designing the rock excavation with a series of slopes and intermediate benches that were superimposed on an overall slope considered to be equivalent to the ultimate stabilized slope after weathering. The relation between the slopes connecting the benches, vertical height between benches and width of benches were designed for initial structural stability as well as performing a proper function during weathering. The benches provide a check for weathered or spalled rock particles and prevent them from falling to the roadway ditch or the roadway itself, which could clog drainage systems or be a danger to traffic.

The benching principle could resolve itself into many geometric standards dependent upon the materials to be excavated. If a few slopes were to be designed, or sufficient time available, it would be desirable to consider all possible variations. However, in the interests of overall standardization for the eighty-eight mile West Virginia Turnpike, and to eliminate costly expenditure of time, a basic set of standard slope designs was established. These standards considered the following variables:

1) Material in the rock slope - sandstone or shale.
2) Overall depth of rock cut.
   a) Sandstone - more or less than 25 feet.
   b) Shale - more or less than 20 feet.
3) Weathering susceptibility of the rock - above or below average.

Shale slopes equal to or less than ten (10) feet in vertical height and sandstone slopes equal to or less than fifteen (15) feet in vertical height were designed for a standard slope without any benching. Intermediate slopes assumed the same superimposed slope with the individual dimensions proportionately reduced. The geometrics of the slope design for these variables were based on recommendations of the West Virginia Road Commission, and may be noted on Figure 1.

The shale slopes were designed for a benching system that resulted in a superimposed slope of one horizontally to one vertically, with an excavated face slope of one horizontally to two vertically for a maximum height between benches of thirty (30) feet and a maximum width of bench of fifteen (15) feet, for all excavations deeper than twenty (20) feet. The sandstone slopes were

2. "The Design of the Slope of Highway Rock Excavations in West Virginia," by R. F. Baker, presented at the 3rd Annual Symposium on Geology as Applied to Highway Engineering, Lexington, Virginia, February, 1952.

designed for a benching system that resulted in a superimposed slope of essentially one horizontally to two vertically, with an excavated face slope of one horizontally to four vertically for a maximum height between benches of forth (40) feet and a maximum width of bench of fifteen (15) feet, for all excavations deeper than twenty-five (25) feet. The controlling depth of excavation for these standards was the greatest depth for any given length of cut.

The properties of the rock materials dictated that the shale slopes should be flatter than the sandstone slopes, for the former are generally more susceptible to weathering as well as having a lower structural stability. Then each class of material and depth of excavation were further subdivided dependent upon the degree of weathering susceptibility, with a resulting modification of the dimensions of the first bench system above the ditch line. These modifications resulted in shifting the superimposed slope back and away from the ditch line for materials indicating above average weathering susceptibility. This allowed for a greater accumulation of weathered particles without increasing maintenance. A more weatherable rock does not necessarily indicate a reduction in structural strength, and it is therefore not economically justifiable to flatten the slopes in such material.

Classification of Weatherability

The overall dimensions of excavation are easily established by grade profile design applied to ground profile and cross-sections. The type of material to be excavated; soil, sandstone or shale, to be encountered is readily determined by core drilling and supporting geophysical surveys. However, some method of evaluating the rock materials with regard to weathering susceptibility had to be devised to economically conform to the standards noted hereinbefore. The rock material itself may be classified by the cores obtained from the diamond core borings, however, these core samples were generally obtained below the zone of weathering and disclose no information in predicting their weathering susceptibility without some possible form of subsidiary testing. The tempo of the project eliminated the feasibility of extensive research to devise a test procedure completely suited to the problem, but the problem was of sufficient importance to eliminate reliance on visual classification and personal opinion of freshly drilled rock core samples to estimate the weathering susceptibility. The subsequent analytical studies supported this contention.

The problem could have been qualitatively resolved by an extensive geological survey, on a statewide basis, wherein each stratum deposit within nine (9) groups of five (5) geological series would be classified as to weathering susceptibility by visual inspection of exposed natural or artificial outcrops. This was obviously an unsatisfactory method of attack because (1) the time and expense required for such a survey was prohibitive and (2) it would be difficult to account for time of exposure, regional variations of climatic conditions and effects of topography.

A compromise solution was selected, embodying both qualitative and quantitative aspects, that would produce adequate results with a minimum of time. Established methods of laboratory procedure were investigated, with a view to modification to allow for comparison to known weathered conditions of rock along the route of the turnpike. This would eliminate the variations of climatic and topographic conditions. The laboratory procedure selected was essentially the A.S.T.M. - A.A.S.H.O. Standard for the magnesium sulfate soundness test of aggregate and rock. This selection was made because of the simplicity of the procedure and the belief that the test closely approximated

accelerated climatic weathering. Abrasion type tests were considered but not selected for they only indicated the resistance of the material to physical impact.[3] Freezing and thawing resistance was not selected because of the required extensive laboratory installations and the time of performance of this test.

Establishment of the Test Procedure

A representative sampling, both geological and topographical, of sandstone and shales was tested in accordance with the magnesium sulfate soundness test to establish a modified test procedure, and to determine applicability to all material types to be encountered. The established A.S.T.M. - A.A.S.H.O. standards of solution saturation, solution temperature, sample preparation and time of immersion were found to be applicable to the materials tested, and thus the modification of test procedure to be determined was the establishment of a standard number of cycles. Magnesium sulfate was used rather than sodium sulfate because the former more readily went into solution and was readily available commercially under its common name of Epsom Salts. These samples, obtained by diamond core drilling and, based on visual examination, representing a wide range of properties, were weighed after each cycle of the test to determine the rate of weighted average weight loss. These results for eleven (11) shales and fifteen (15) sandstones are graphically represented in Figure 2. As can be seen from this figure, two (2) cycles for shale and five (5) cycles for sandstone, for the samples tested, provided quantitative results of a sufficiently wide range. For the shale samples tested, the percent of weight loss at two (2) cycles varied between 2% and 100% with an approximate average of 45%, and the loss for the sandstone tested at five (5) cycles varied between 0% and 100% with an approximate average of 30%. Figure 2 indicates that many materials tested by this method did not exhibit a uniform rate of weight loss. It was appreciated that this rate of loss, for some materials, appreciatively changed when the cycles were increased beyond the standards indicated. However, it was not the intent of these studies to evaluate or compare the number of cycles of the test procedure to years of natural open exposure to weather. Neither was it intended that the rate of weight loss be correlated to a natural weathering weight loss per unit of area per unit of time. Such evaluations, if at all possible, could only be achieved through long term field investigations. Therefore, the selection of limiting standards for the number of test cycles was based on the apparent minimum that would provide a sufficient distribution of results on the overall average for the materials tested, assuming that these materials represented a reasonable sampling.

The magnesium sulfate soundness test is performed on a sample of approximately 500 grams, consisting of five (5) individual pieces weighing approximately 100 grams each. An additional problem in establishing the modified test procedure was the selection of a standard for determining what portion of the test samples constituted a weathering loss. Sandstones were generally affected by the test procedure in surface etching and spalling, checking and splitting. Shale samples generally split along laminations, cracked, slaked or disintegrated completely. The more resistant sandstones and the less resistant shales, and those materials that were affected by surface etching or spalling presented little problem for the original sample fraction, if

3. "The Utilization of Shales for Highway Purposes," L. Berger, etal, Pennsylvania State College, May, 1949.

any, was easily recognizable. The sandstones that were affected by large cubical splitting and shales that split along planes of lamination, however, required extensive standard definition for selection of that portion representing weight loss. The definition of such weight loss resulted in any portion for a 100 gram sample fraction from a massive deposit that had split into three or more pieces of approximately uniform volume was considered as a loss, but portions of each sample fraction that split along planes of lamination were only considered as a loss when they had a cross-sectional area less than two-thirds (2/3) of the original cross-sectional area of the cored sample.

In the selection of a total sample, the five (5) fractions were not necessarily immediately adjacent as retrieved from the core boring. The five fractions were chosen such as to be representative of an entire strata. In this manner, it was possible to account for shale or coal intrusions in sandstone, or for shales that were constructed of non-uniform lamination thickness. The non-homogenous character of such samples was undoubtedly a factor in the non-uniform rate of weight loss as discussed hereinbefore. Figures 3, 4 and 5 show examples of the action of the magnesium sulfate soundness test on varying sample types.

Field Calibration of Laboratory Results

Once the modified laboratory procedure was established, it was then possible to standardize the results of the test procedure to specific slope design by a qualitative evaluation of existing weathered outcrops of rock. It must be kept in mind that the end result of these studies was to establish a rapid and reasonable method of determining the difference between two degrees of weathering susceptibility, above or below average, to assist in the design of excavation slopes in rock. Therefore, it was necessary to establish the relation between average weathering of an exposed rock surface and the percentage of loss of a rock sample subjected to the established magnesium sulfate soundness test.

This relation, or calibration, was achieved by testing rock core samples that corresponded to existing outcrops in close proximity of the turnpike alignment, that could be qualitatively evaluated with respect to natural weathering susceptibility. The weathering susceptibility of any existing rock slope was qualitatively established on an arbitrary scale from no weathering at "0" to complete disintegration at "10", with an average condition at "5." The qualitative range of this scale may be noted on Figure 6. These scales, though using the same descriptive and numerical values, were not equal for sandstones and shales. They were comparative only within the ranges for each material classification. Thus the average weathering loss for a shale was considerably greater than the average weathering loss for a sandstone. In other words, if the weathering of existing outcrops were quantitatively measured in a weight per unit area per unit time, an average shale would provide a greater numerical value than an average sandstone. The apparent inequality was appreciated in the beginning and considered when establishing the standards of slope design (Figure 1).

The materials for this calibration were selected by a field investigation, independent of the materials used for establishing the test procedure, whereby exposed rock slopes that appeared to have approached a stable weathering condition were evaluated to the arbitrary qualitative scale by a committee of at least two persons, one of whom was a geologist. Only those slopes that were relatively uniform in rock character, and that could be sampled in an unweathered state by core borings were employed in the study. These

samples were then tested for weight loss by the magnesium sulfate method.

The comparison between the quantitative laboratory results and the qualitative field evaluations for sandstones and shales contiguous to the turnpike alignment may be noted on Figure 6. These indicate that a percentage weight loss of about 30-35% by the magnesium sulfate test for five (5) cycles corresponds to an average field weathering for a sandstone, and that a percentage weight loss of 40-50% by the magnesium sulfate test for two (2) cycles corresponds to an average field weathering for a shale.

Design Application

Once these limits had been determined, all rock core samples obtained from borings for roadway excavation were visually classified. The various geologic series and their subgroups were considered in this classification, by use of the excellent county geologic maps available. Then at least one representative sampling of each material or strata to be encountered in excavation was tested in accordance with the modified magnesium sulfate soundness test, and the results applied to the final design of backslopes for each cut. Where initial laboratory results indicated an average material with regard to weathering classification, additional tests on similar samples were necessary to reach the final decision as to design for above average or below average weathering susceptibility.

In many cases, the stratified subsurface conditions necessitated comparative consideration of material content of the slope before final design could be effected. When a predominance of one type of material in an interbedded sandstone and shale was disclosed with no particular demarcation of a massive strata, the slope was designed in accordance with the predominant material, with a weighted average of the weathering classification considered. As an example, consider a rock formation of predominantly sandstone with below average weathering susceptibility with interbedded shale strata with a below average weathering susceptibility. This would then be designed as a sandstone slope with above average weathering susceptibility.

There were also extreme conditions encountered such as a light brown, poorly-cemented, medium-fine grain sandstone that exhibited a loss of weight of 27% in two (2) cycles, 95% in four (4) cycles and completely disintegrated in five (5) cycles. This sandstone was considered as a soil rather than a rock when the excavation backslopes were designed. Elsewhere a material that was visually classified as a dark grey, massive, sandy shale or sandy clay rock was encountered, that exhibited a loss of only 13% after five (5) cycles of the magnesium sulfate test. This massive deposit was considered as a poor sandstone rather than a good shale when the backslopes were designed.

CONCLUSIONS

It is appreciated that these limited studies were based on the bold assumption that there is a direct correlation between field weathering action and the magnesium sulfate soundness test as performed in the laboratory. There is no known data to support this assumption and it is possibly incorrect. As such, no specific conclusions may be drawn. However, the character of the project demanded applied study, such as described, even though there was a deficiency of preceding basic research. The evaluation of methods and results was a collective consideration of many participating persons, but the character of the study was such that it was still possibly subject to some degree of

personal error. Nevertheless, because the end result of this investigation was the determination of the limit between two general conditions, above average and below average weathering susceptibility, it is believed that it was entirely adequate as a guide in engineering judgment.

ACKNOWLEDGMENTS

Considerable credit must be given to Mr. R. F. Baker, Engineer of Soil Mechanics, State Road Commission of West Virginia, who has made extensive studies of landslides in West Virginia. His recommendations were considered in establishing the dimensions of the backslopes as used on this project. He was also a valuable consultant throughout these studies. These studies were under the direction of the firm of Howard, Needles, Tammen & Bergendoff in the capacity of General Consultants to the West Virginia Turnpike Commission. Capitol Engineering Corporation; Fay, Spofford & Thorndike; and Gannett, Fleming, Corddry & Carpenter, Inc., in the capacity of Section Consulting Engineers to the Turnpike Commission, assisted in these studies and employed the results in the roadway design.

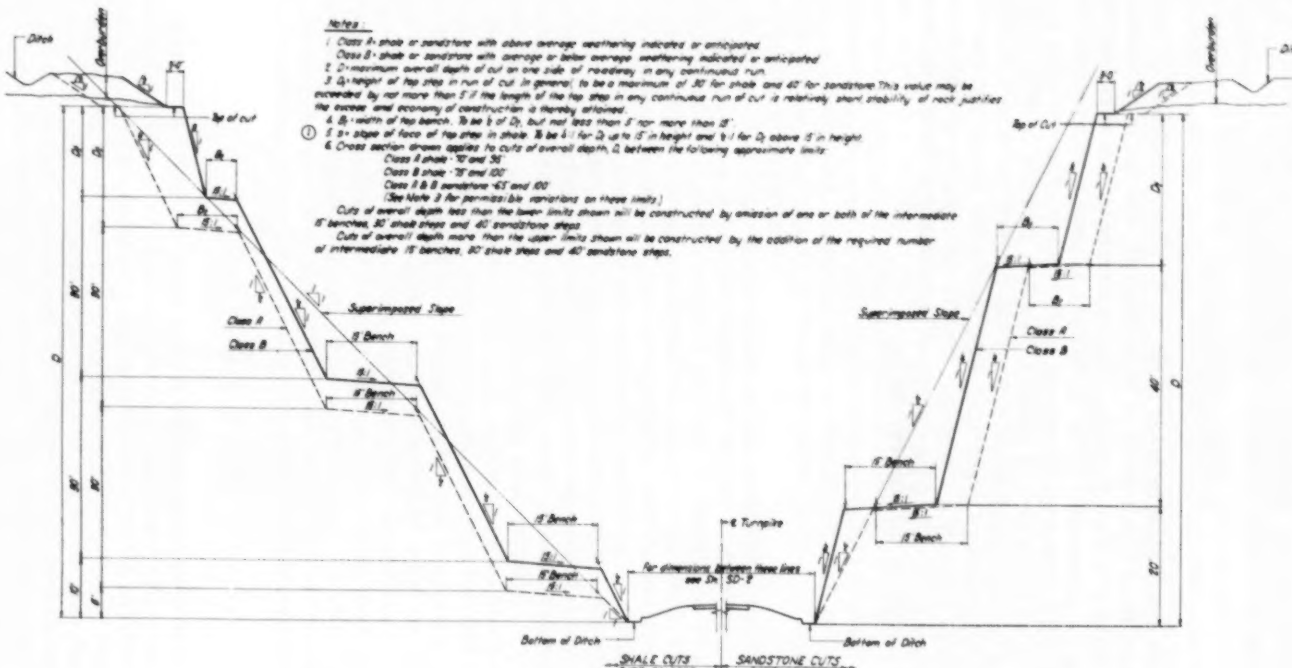


FIGURE 1

TYPICAL CROSS SECTION
CLASS I CUTS
1" = 10'-0"

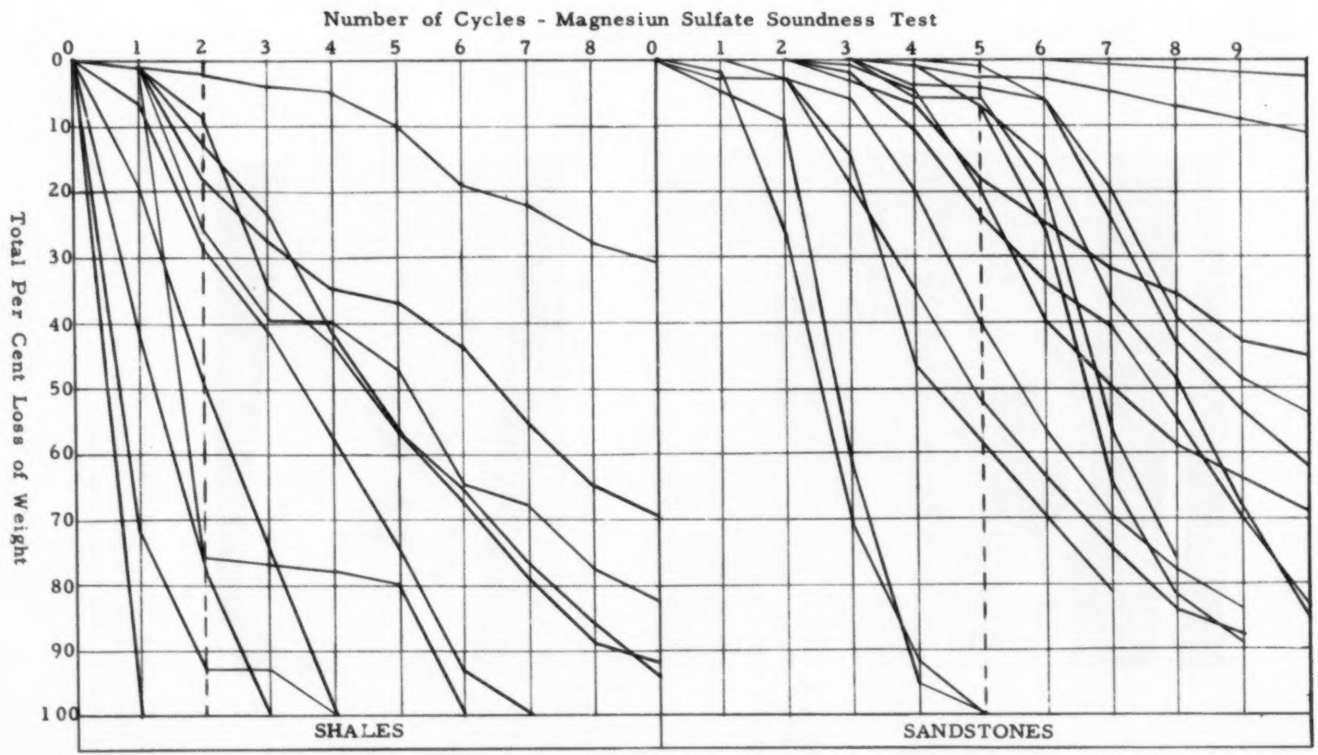


FIGURE 2. RATE OF WEIGHT LOSS FOR COMPARATIVE ACCELERATED WEATHERING IN ESTABLISHMENT OF TEST PROCEDURE

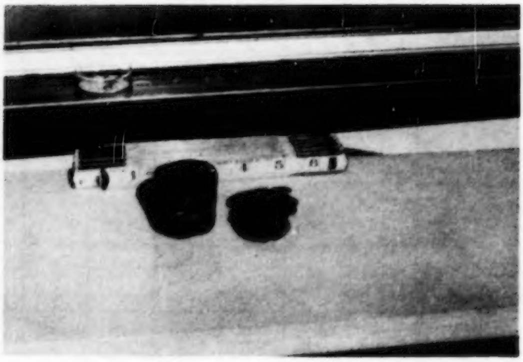


FIGURE 3. A 100 gram fraction of a laminated sandstone, before and after subjection to five (5) cycles of magnesium sulfate soundness test.

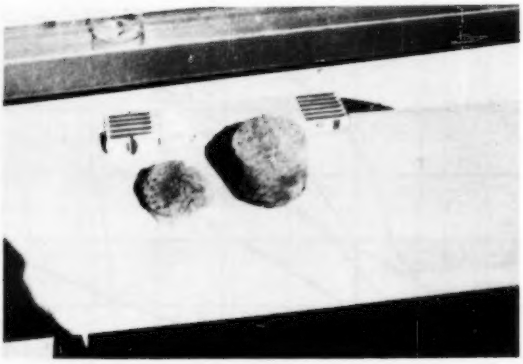
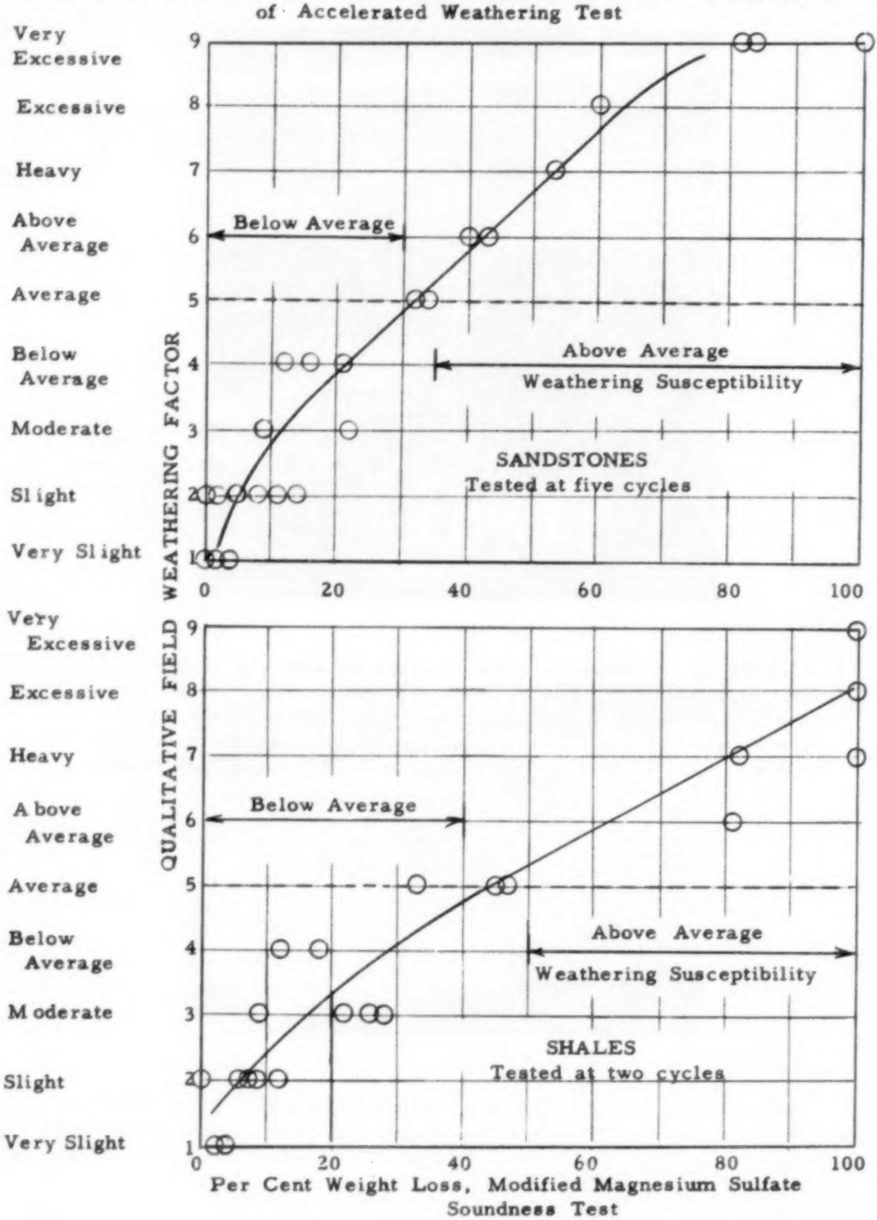


FIGURE 4. A 100 gram fraction of a grey, fine grained, hard sandstone, before and after subjection to five (5) cycles of magnesium sulfate soundness test.

FIGURE 5. A series of core samples at different stages of disintegration after removal from the drying oven. Each row consists of the five fractions of a sample that has been dried in a separate glass dish. Immersion in the magnesium sulfate solution is performed in the compartmented wire basket shown.

FIGURE 6. ROCK WEATHERING CLASSIFICATION

Correlation of Qualitative Field Weathering Factor to Laboratory Results of Accelerated Weathering Test



PROCEEDINGS PAPERS

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

VOLUME 80 (1954)

JULY: 457(AT), 458(AT), 459(AT)c, 460(IR), 461(IR), 462(IR), 463(IR)c, 464(PO), 465(PO)c.

AUGUST: 466(HY), 467(HY), 468(ST), 469(ST), 470(ST), 471(SA), 472(SA), 473(SA), 474(SA), 475(SM), 476(SM), 477(SM), 478(SM)c, 479(HY)c, 480(ST)c, 481(SA)c, 482(HY), 483(HY).

SEPTEMBER: 484(ST), 485(ST), 486(ST), 487(CP)c, 488(ST)c, 489(HY), 490(HY), 491(HY)c, 492(SA), 493(SA), 494(SA), 495(SA), 496(SA), 497(SA), 498(SA), 499(HW), 500(HW), 501(HW)c, 502(WW), 503(WW), 504(WW)c, 505(CO), 506(CO)c, 507(CP), 508(CP), 509(CP), 510(CP), 511(CP).

OCTOBER: 512(SM), 513(SM), 514(SM), 515(SM), 516(SM), 517(PO), 518(SM)c, 519(IR), 520(IR), 521(IR), 522(IR)c, 523(AT)c, 524(SU), 525(SU)c, 526(EM), 527(EM), 528(EM), 529(EM), 530(EM)c, 531(EM), 532(EM)c, 533(PO).

NOVEMBER: 534(HY), 535(HY), 536(HY), 537(HY), 538(HY)c, 539(ST), 540(ST), 541(ST), 542(ST), 543(ST), 544(ST), 545(SA), 546(SA), 547(SA), 548(SM), 549(SM), 550(SM), 551(SM), 552(SA), 553(SM)c, 554(SA), 555(SA), 556(SA), 557(SA).

DECEMBER: 558(ST), 559(ST), 560(ST), 561(ST), 562(ST), 563(ST)c, 564(HY), 565(HY), 566(HY), 567(HY), 568(HY)c, 569(SM), 570(SM), 571(SM), 572(SM)c, 573(SM)c, 574(SU), 575(SU), 576(SU), 577(SU), 578(HY), 579(ST), 580(SU), 581(SU), 582(Index).

VOLUME 81 (1955)

JANUARY: 583(ST), 584(ST), 585(ST), 586(ST), 587(ST), 588(ST), 589(ST)c, 590(SA), 591(SA), 592(SA), 593(SA), 594(SA), 595(SA)c, 596(HW), 597(HW), 598(HW)c, 599(CP), 600(CP), 601(CP), 602(CP), 603(CP), 604(EM), 605(EM), 606(EM)c, 607(EM).

FEBRUARY: 608(WW), 609(WW), 610(WW), 611(WW), 612(WW), 613(WW), 614(WW), 615(WW), 616(WW), 617(IR), 618(IR), 619(IR), 620(IR), 621(IR)c, 622(IR), 623(IR), 624(HY)c, 625(HY), 626(HY), 627(HY), 628(HY), 629(HY), 630(HY), 631(HY), 632(CO), 633(CO).

MARCH: 634(PO), 635(PO), 636(PO), 637(PO), 638(PO), 639(PO), 640(PO), 641(PO)c, 642(SA), 643(SA), 644(SA), 645(SA), 646(SA), 647(SA)c, 648(ST), 649(ST), 650(ST), 651(ST), 652(ST), 653(ST), 654(ST)c, 655(SA), 656(SM)c, 657(SM)c, 658(SM)c.

APRIL: 659(ST), 660(ST), 661(ST)c, 662(ST), 663(ST), 664(ST)c, 665(HY)c, 666(HY), 667(HY), 668(HY), 669(HY), 670(EM), 671(EM), 672(EM), 673(EM), 674(EM), 675(EM), 676(EM), 677(EM), 678(HY).

MAY: 679(ST), 680(ST), 681(ST), 682(ST)c, 683(ST), 684(ST), 685(SA), 686(SA), 687(SA), 688(SA), 689(SA)c, 690(EM), 691(EM), 692(EM), 693(EM), 694(EM), 695(EM), 696(PO), 697(PO), 698(SA), 699(PO)c, 700(PO), 701(ST)c.

JUNE: 702(HW), 703(HW), 704(HW)c, 705(IR), 706(IR), 707(IR), 708(IR), 709(HY)c, 710(CP), 711(CP), 712(CP), 713(CP)c, 714(HY), 715(HY), 716(HY), 717(HY), 718(SM)c, 719(HY)c, 720(AT), 721(AT), 722(SU), 723(WW), 724(WW), 725(WW), 726(WW)c, 727(WW), 728(IR), 729(IR), 730(SU)c, 731(SU).

JULY: 732(ST), 733(ST), 734(ST), 735(ST), 736(ST), 737(PO), 738(PO), 739(PO), 740(PO), 741(PO), 742(PO), 743(HY), 744(HY), 745(HY), 746(HY), 747(HY), 748(HY)c, 749(SA), 750(SA), 751(SA), 752(SA)c, 753(SM), 754(SM), 755(SM), 756(SM), 757(SM), 758(CO)c, 759(SM)c, 760(WW)c.

c. Discussion of several papers, grouped by Divisions.